Impact of Semiconductor Technology on Aerospace Electronic System Design, Production, and Support

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Avionics Experiences: 1990-Present

Early 1990s: COTS Parts
Mil-spec mfrs. exit market

We "succeeded" because COTS parts were more reliable than we had thought, and because of improvements in quality and reliability

Mid 1990s: DMS
60% of parts are obsolete within 5 years

We are "coping" through aggressive responses, and beneficial, but temporary circumstances

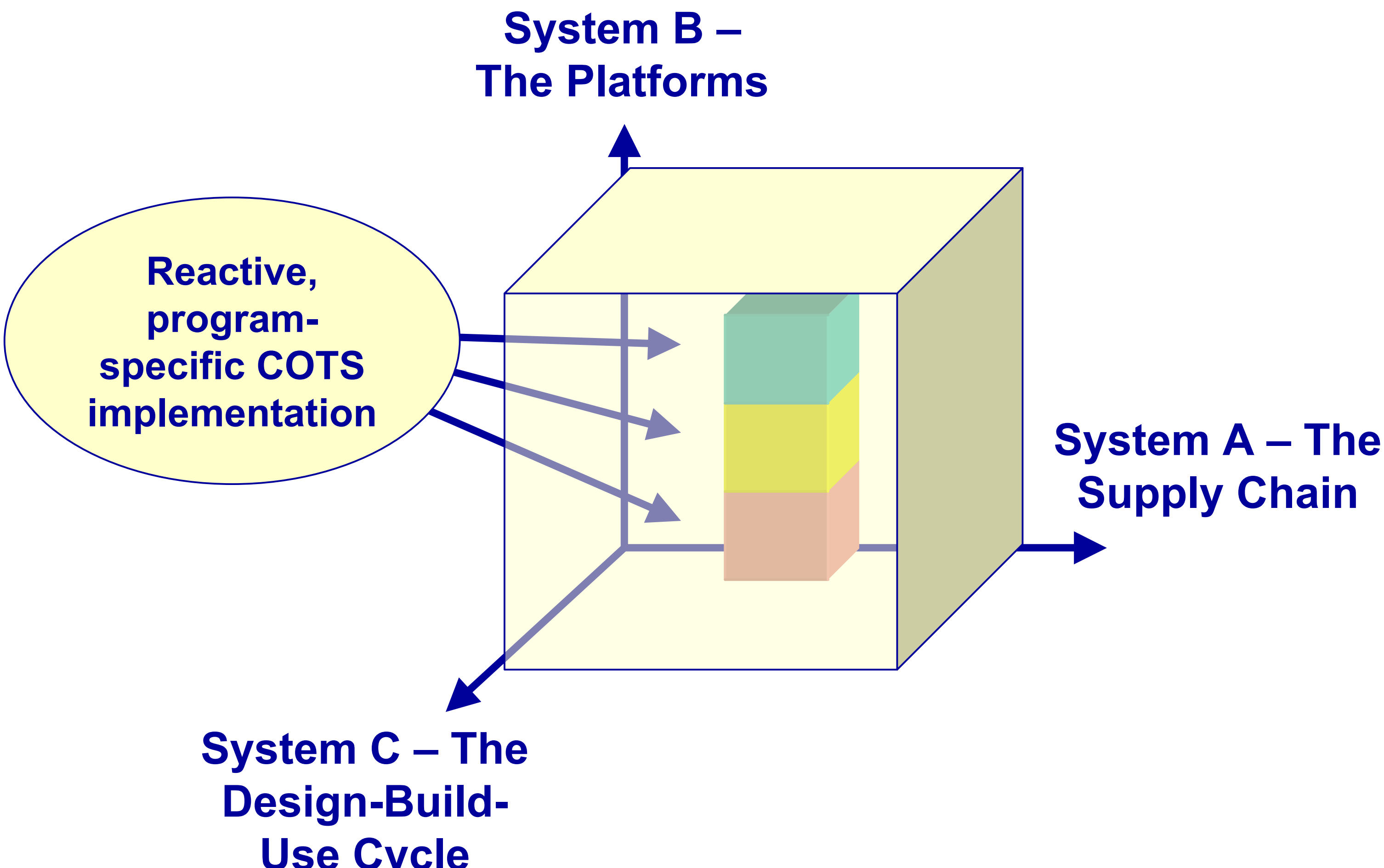
Today: Nanometer Scale
3-7 yr. life, targeted products

We cannot "succeed" or "cope" with tactics that we have used in the past

- Tactical, short-term, and ad hoc solutions
- Each "solution" introduces a future DMS problem.

Strategic, long-term solution based on cooperation between semiconductor device and avionics industries

COTS-DMS-Obsolescence must be addressed as system-of-systems problem



Outline

- Structural Changes in the Avionics Supply Chain
- Technological Advances in the Semiconductor Device Industry
- Part Level Solutions
- System and Architectural Solutions
- Summary

Challenges

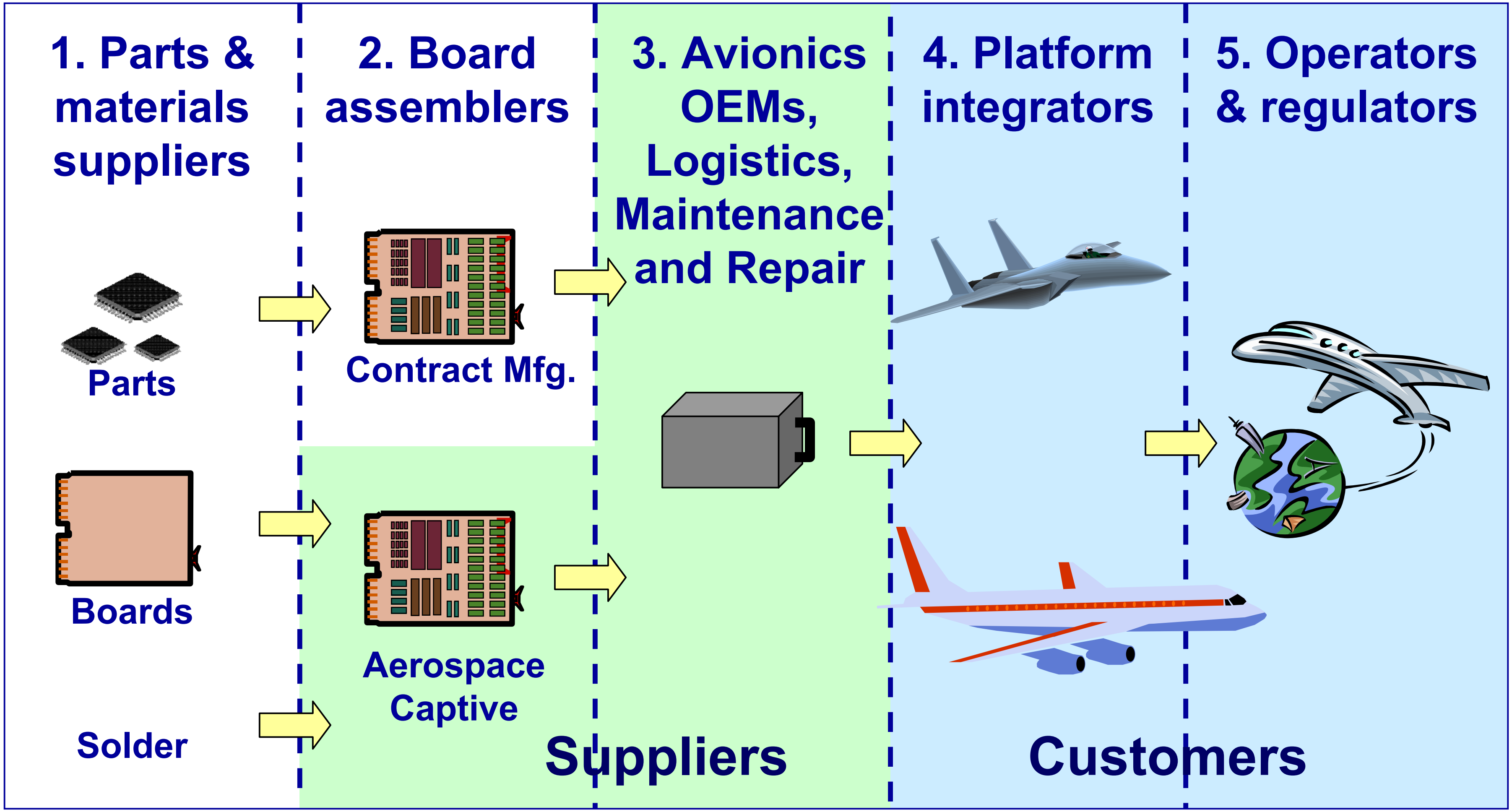
Structural Changes in the Avionics Supply Chain

- Migration away from military and aerospace markets
- Growth of the Asian electronics industry
- Semiconductor product definition and design processes
- Elimination of lead and other hazardous materials

Technological Advances in the Semiconductor Device Industry (< 100nm technology)

- Short service life (3-10 years)
- Narrow Temperature Ranges
- Susceptibility to atmospheric radiation

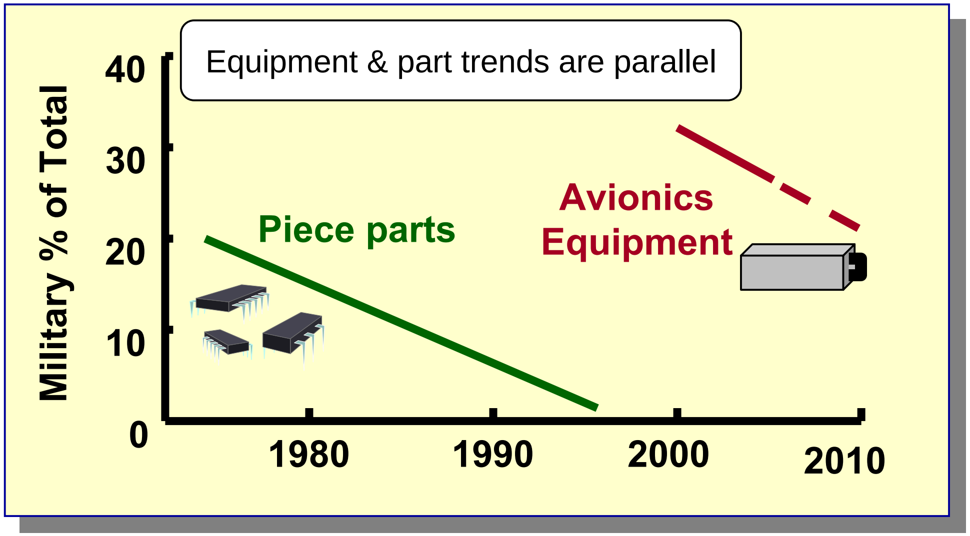
The Aerospace Electronics Supply Chain



Non-aerospace Control

Aerospace Control

The Global Electronics Market



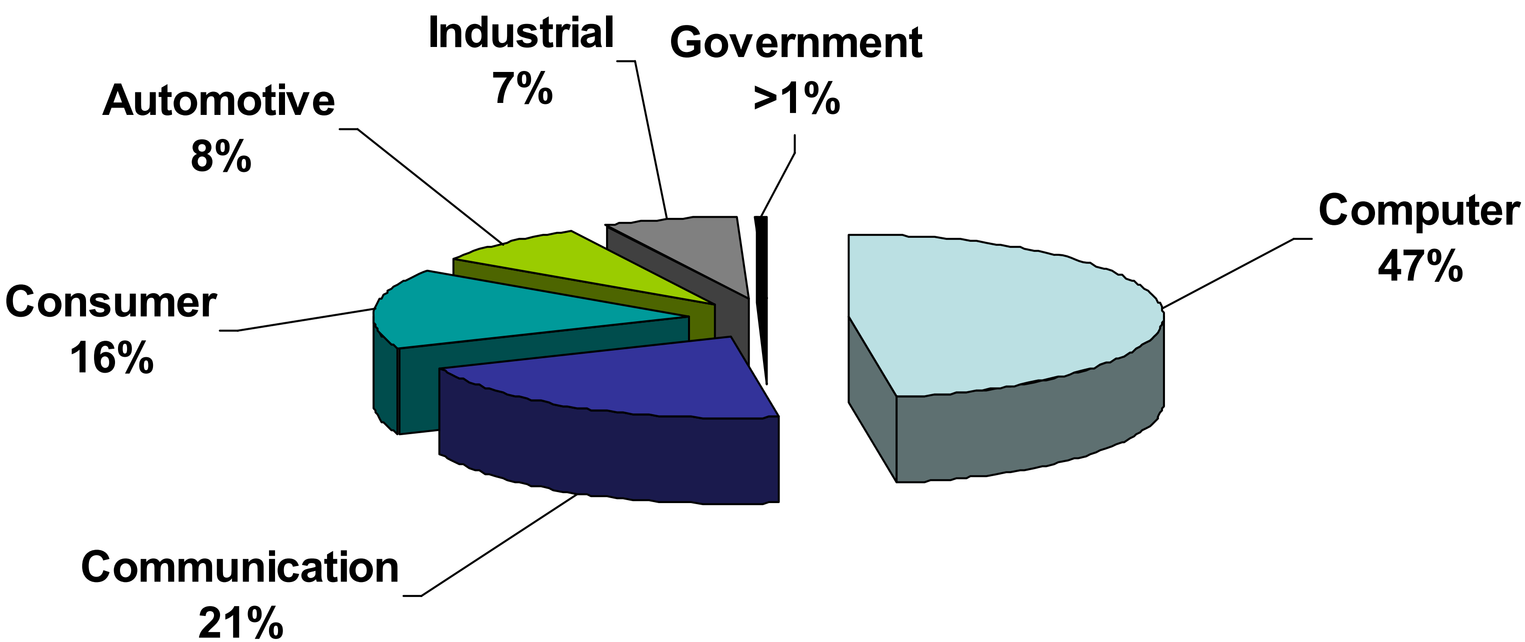
Space – <1%

Worldwide Semiconductor Markets:

Military and Aerospace market share declined for 4½ Decades

- **1995 = 1.6%   2002 = .5%**
- **1994 Perry Directive accelerated COTS usage and Military IC demise**
- **Asia-Pacific market surpassed US in 2002; gap will widen Military &**

Aerospace User's best hope = appear as ONE customer!

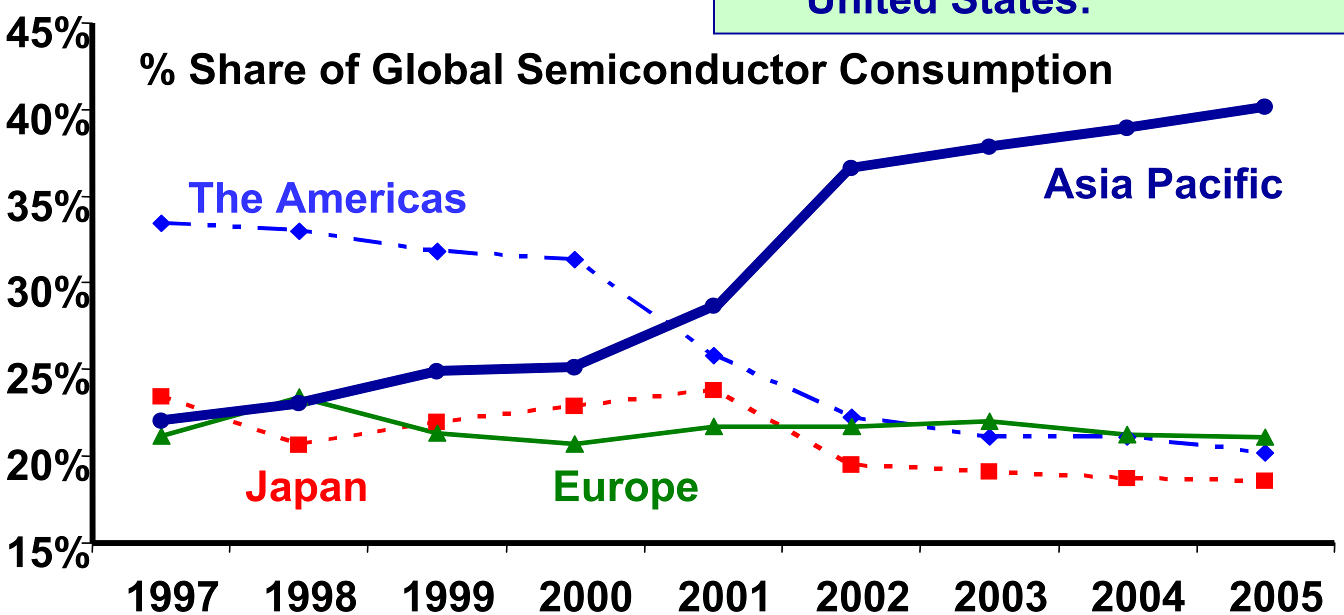


Source: Semiconductor Industry Association

Global Markets

The World's Largest Markets, by population:

China:	1,300,000,000
India:	1,065,000,000
European Union:	457,000,000
United States:	295,000,000

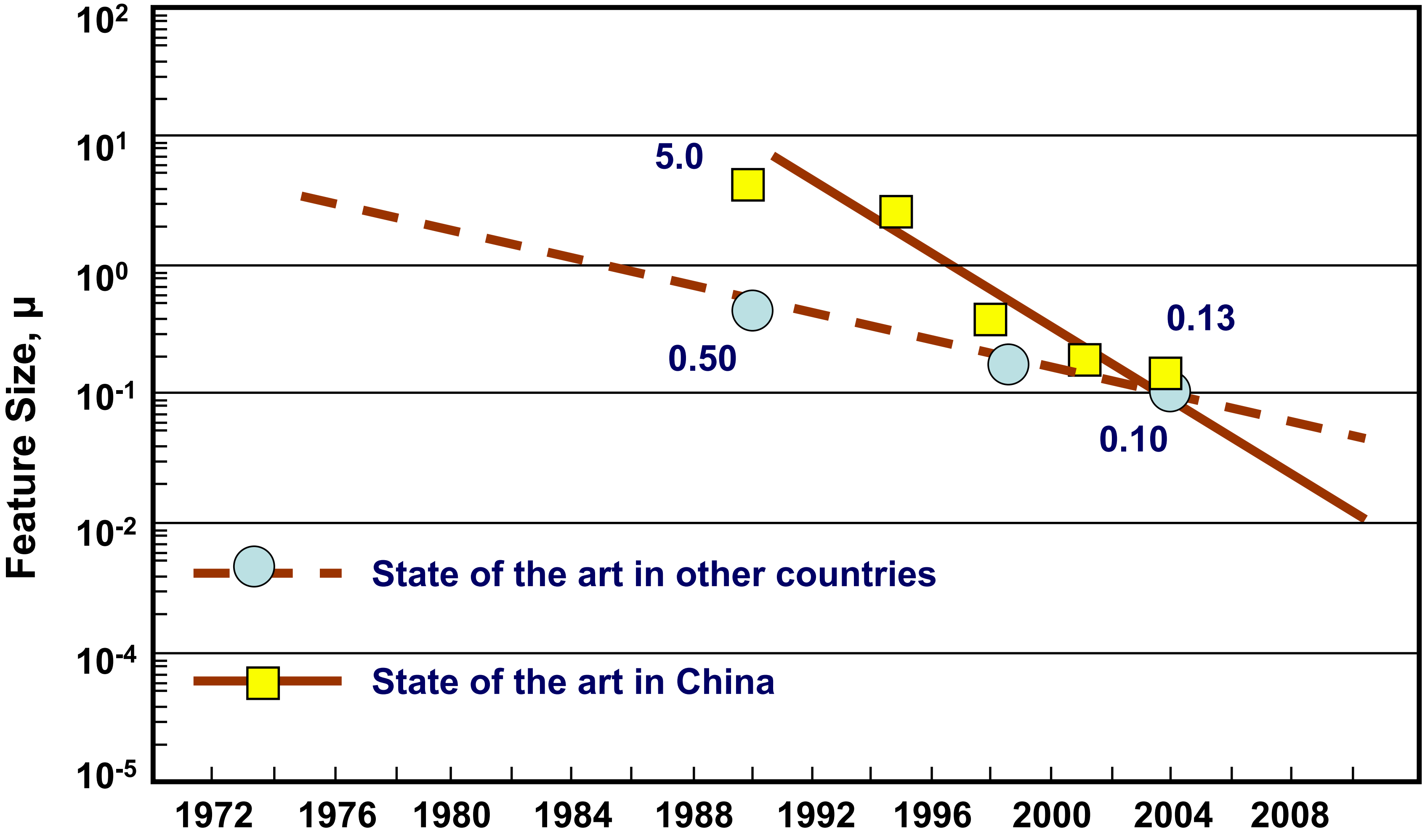


Source: WSTS/SIA

"China's technological growth is phenomenal. The rapid development of semiconductor technologies is a measure of China's success in obtaining and advancing technologies. The U.S. focus has been on war and security issues, while loss of technological dominance decreases future economic power."

M.G. Pecht, IEEE Transactions on CPT, 09/2004

China's Technology is Catching Up Rapidly

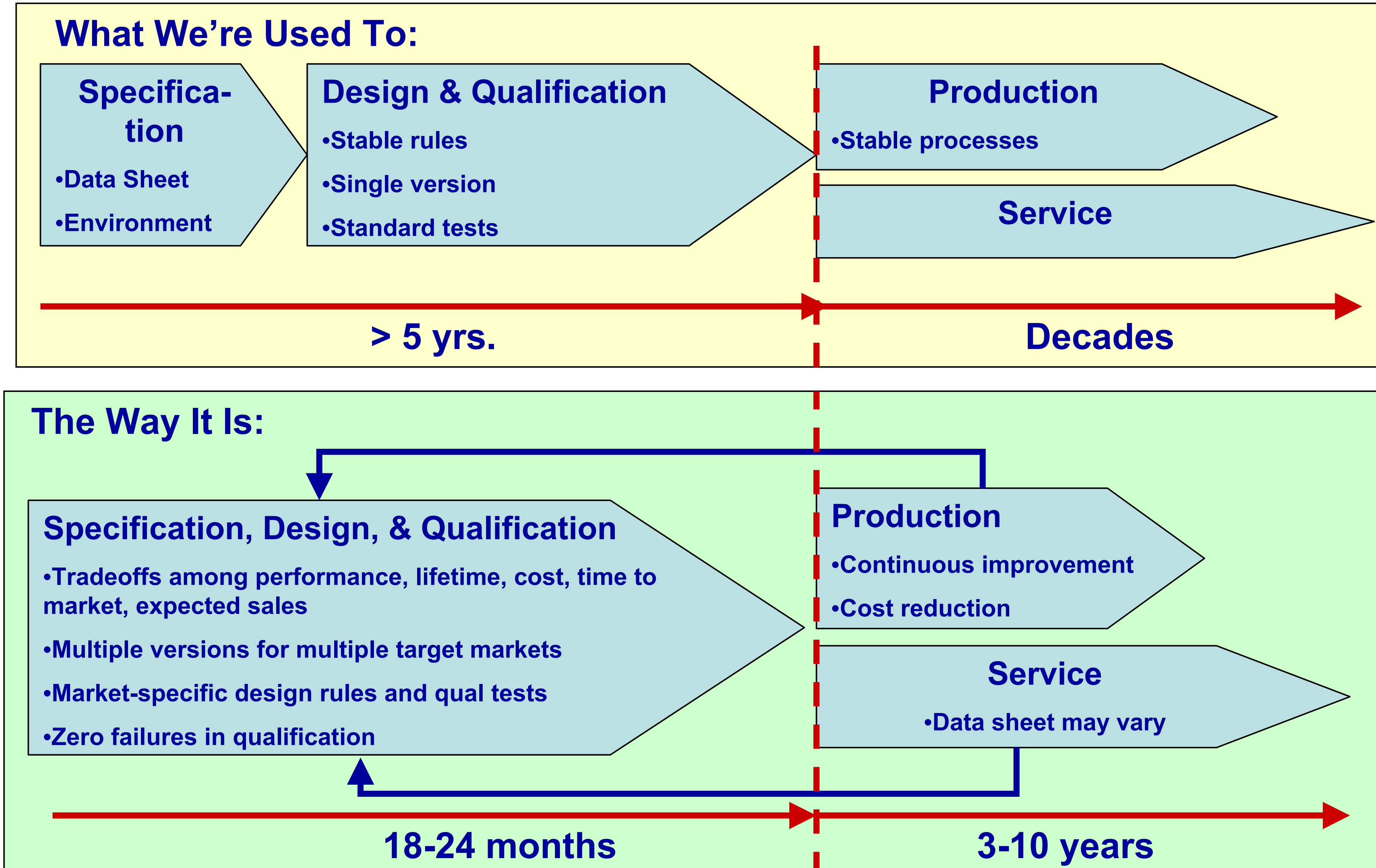


Source: M.G. Pecht, IEEE Transactions on Components and Packaging Technologies, September 2004

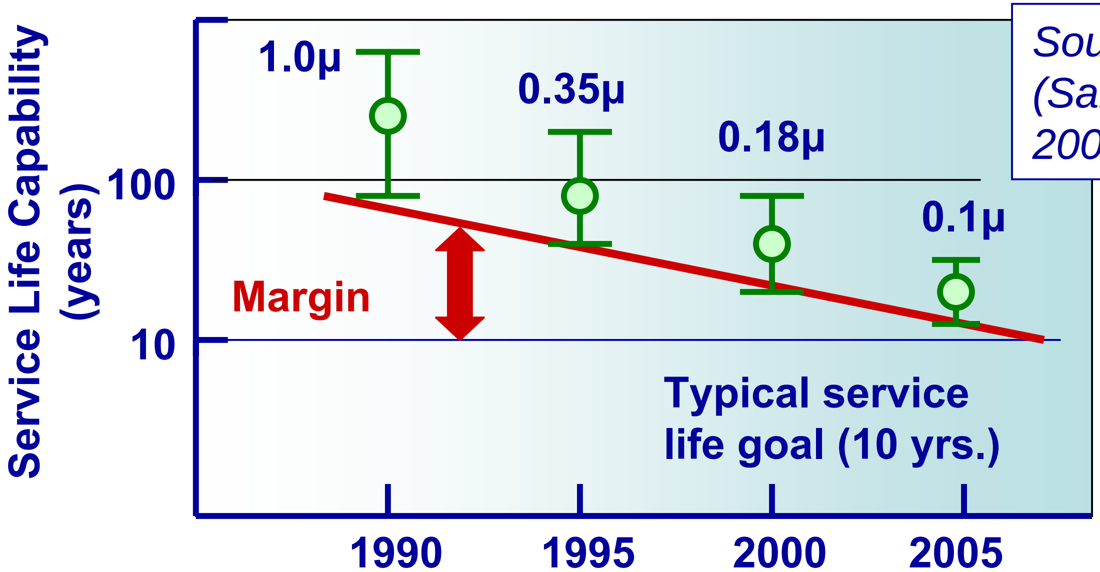
Semiconductor Device Design

- Tradeoffs made among
  - Performance (speed, no. of transistors, etc.)
  - Reliability (lifetime)
  - Cost (die/wafer, yield, etc.)
  - Time to market
  - Expected sales volume and market share
- Different design rules for different market segments
- Design rules adjusted to ‘equalize’ wearout mechanisms
- Data sheet ‘negotiated’ among engineering, marketing, accounting
- Tests performed to assure minimum performance and ‘acceptable probability of reliability’
  - Acceptance criterion is ‘zero failures’
  - Performance and reliability capability not investigated beyond above requirements
  - Specific models used to accelerate key failure mechanisms
- Device put on market
- Immediate work is started on performance enhancement and cost reduction
- Published data sheet parameters may not exactly match actual device performance

Microcircuit Design

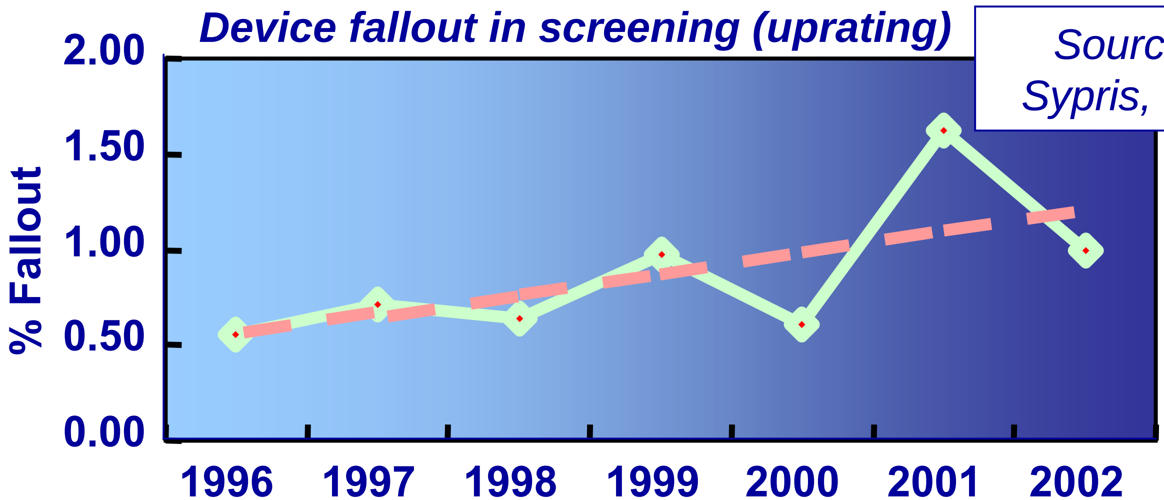


Disappearing Margins



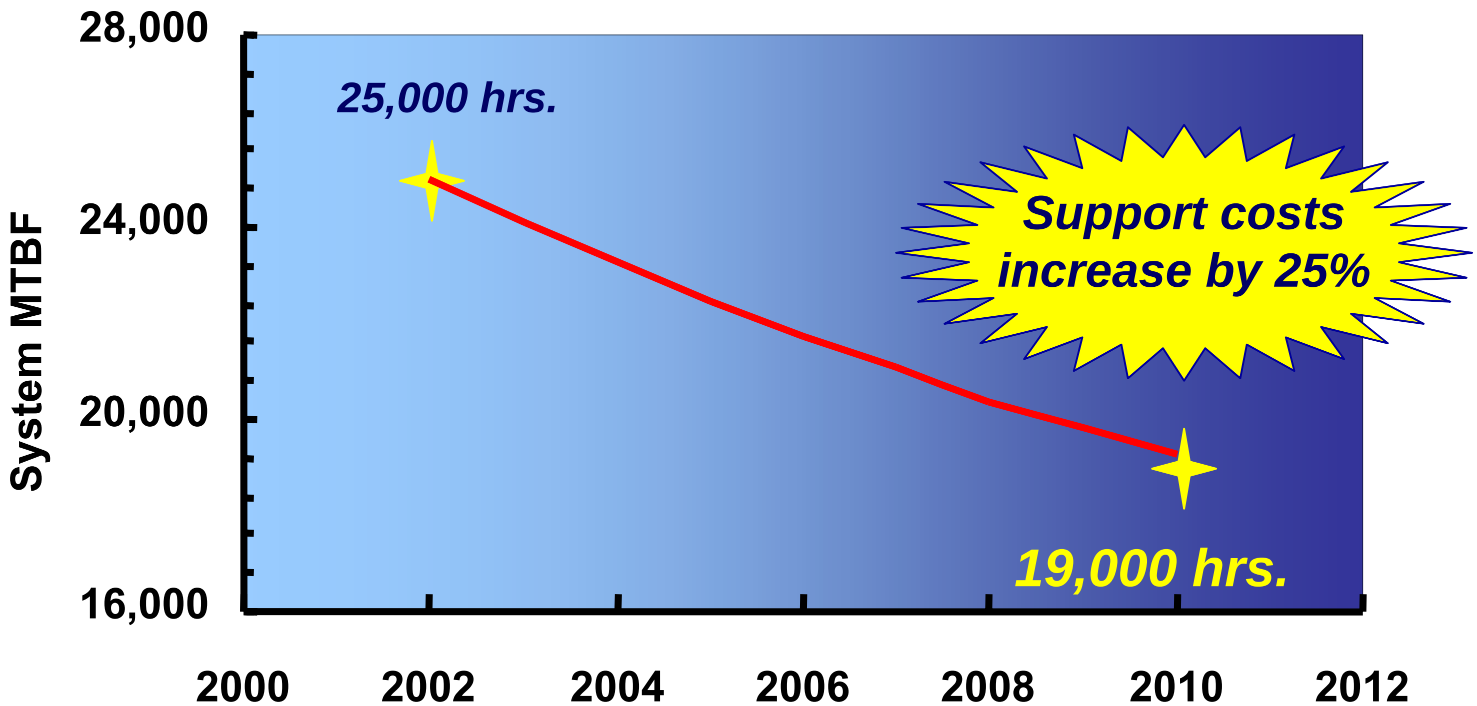
Source: E. Snyder (Sandia), IRPS, 2002)

Most semiconductor devices are designed with 3-10 year service life goals



Source: Sypris, Inc.

Impact on System Reliability



Assumptions:

- **System includes 1,000 equivalent semiconductor devices, and system MTBF of 25,000 hours in 2002**
- **Decrease in system MTBF due only to increase in semiconductor device failure rate**
- **Device failure rate increases by >1.5 FITs per year**

Semiconductor Device Wearout Models

- Electromigration: migration of atoms in a conductor (Black's equation)

$$\mathrm{MTTF} = A j_e^{-n} \exp\left(\frac{E_a}{kT}\right)$$

- Hot Carrier Effects: high energy carriers degrade oxide; Lifetime related to drain voltage & V_{dd}

$$\mathrm{MTTF} = C \exp\left(\frac{B}{V_{dd}}\right)$$

- Oxide Breakdown (TDDB): Formation of a conduction path through gate oxide

$$\mathrm{MTTF} = D \exp\left(\frac{E_a}{kT} - \gamma \varepsilon_{ox}\right)$$

Preliminary Results:

System Design Tradeoffs

Time-dependent dielectric breakdown

$$D_{fTDDB} = \exp\left(\gamma\varepsilon_{ox}\left(1 - \frac{V_{dd}}{V_{dd,\max}}\right)\right) x \exp\left(\left(\frac{E_{aTDDB}}{k}\right)\left(\frac{1}{T_j} - \frac{1}{T_{j,\max}}\right)\right)$$

Electromigration

$$D_{fEM} = \left(\frac{V_{dd,\max}}{V_{dd}}\right)^n \exp\left(\left(\frac{E_a}{k}\right)\left(\frac{1}{T_j} - \frac{1}{T_{j,\max}}\right)\right)$$

Hot carriers

$$D_{fHCD} = \exp\left(B\left(\frac{1}{V_{dd}} - \frac{1}{V_{dd,\max}}\right)\right)$$

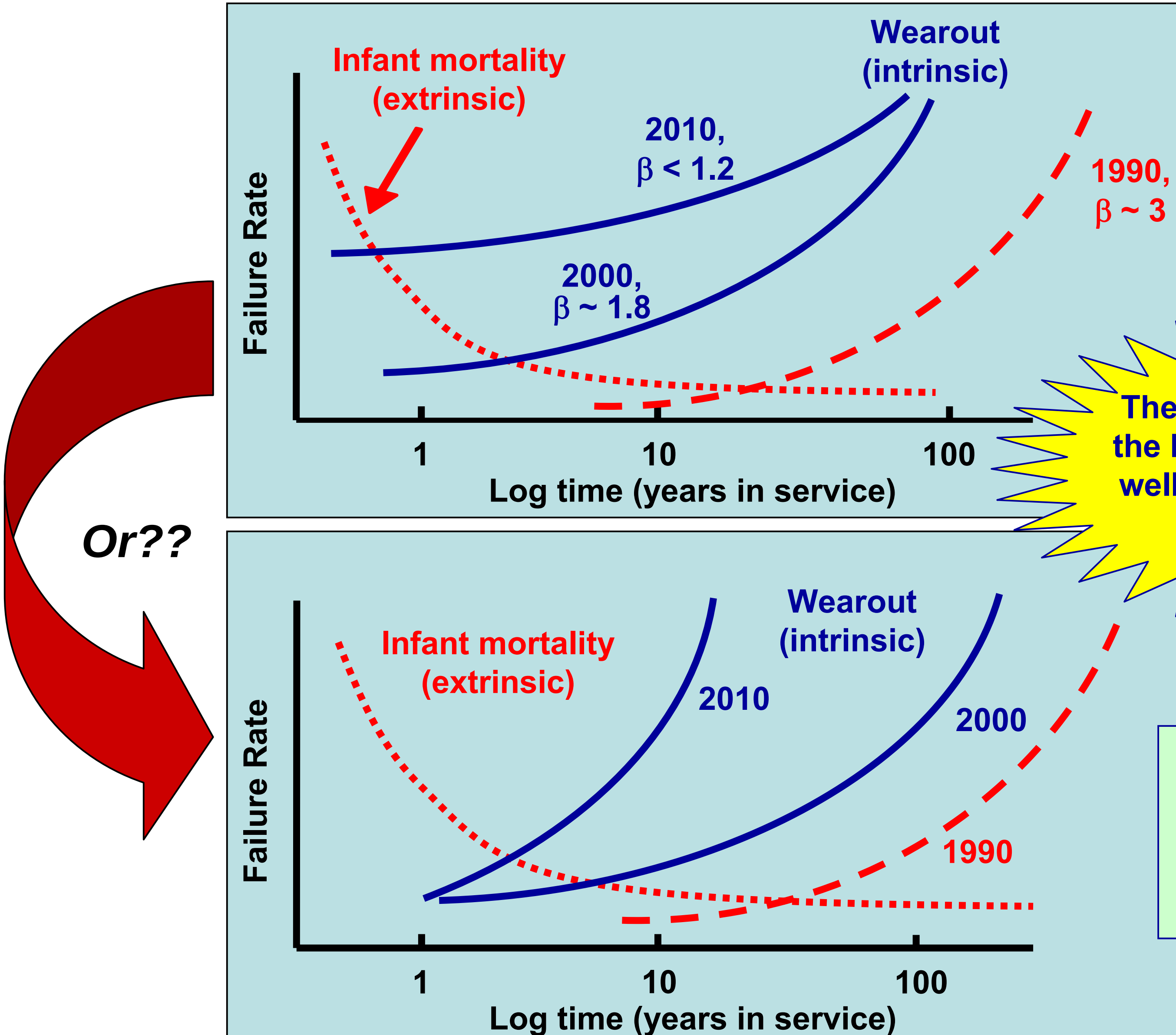
All mechanisms

$$D_f = \frac{\lambda}{\frac{\lambda_{EM}}{D_{fEM}} + \frac{\lambda_{HCD}}{D_{fHCD}} + \frac{\lambda_{TDDB}}{D_{fTDDB}}}$$

Within limits, tradeoffs may be made among lifetime, speed, voltage, and temperature.

D is the "derating factor," i. e., the ratio of lifetime at "derated" conditions (voltage, temperature) to that at "data sheet" conditions.

The Meaning of Life?



The wearout portion of the bathtub curve is not well-understood, and it varies among manufacturers

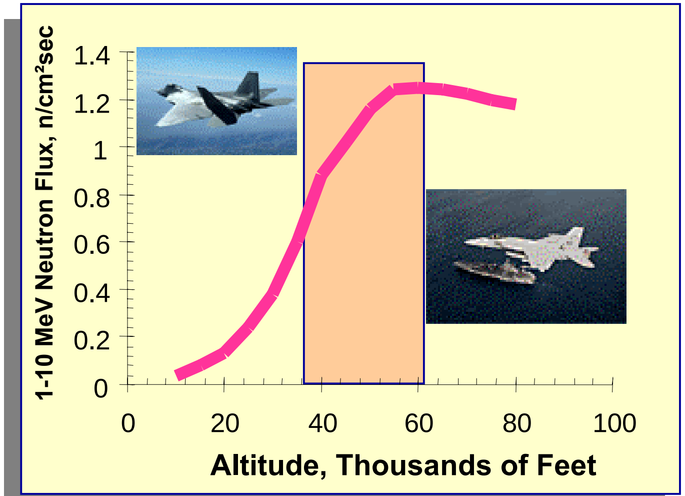
There is not yet a compelling reason to change system safety and reliability analysis processes

Effects of Atmospheric Radiation

Technology Node, nm	Sensitive Volume (Si), μ^3	Sensitive Depth (SOI), μ	Critical Charge (Si), fC
250	0.245	0.15	8
130	0.025	0.15	2.5
90	0.01	0.07	1.2
65	0.0035	0.05	0.8

P. Roche, G. Gasiot, K. Forbes, V. O'Sullivan, V. Ferlet, "Comparisons of Soft Error Rate for SRAMs in Commercial SOI and Bulk Below the 130 nm Technology Node," 2003 IEEE Nuclear and Space Radiation Effects Conference.

Current estimates for SEU rates are probably conservative by >2x



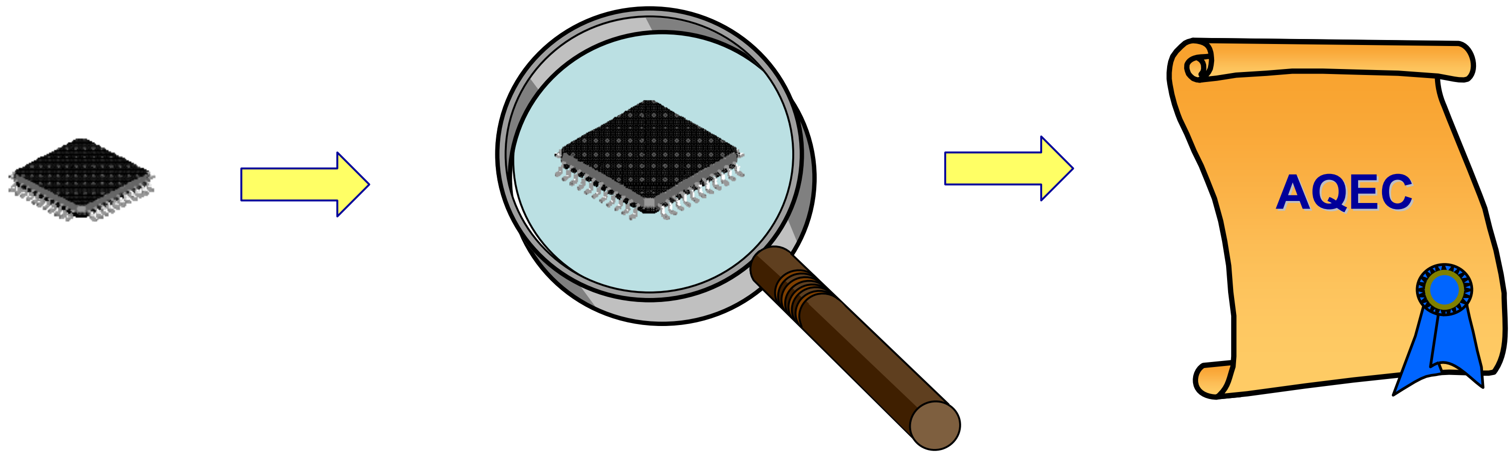
Almost all testing is done on memories, but some tests on processors indicate they may be more susceptible to atmospheric radiation

Test "portability" is not assured

Avionics Industry Response to Effects of Atmospheric Radiation on System Design

- Use error-correcting code
- Increase part redundancy
- May have to increase testing
- Use the methods of IEC TS 62396, *Standard for the Accommodation of Atmospheric Radiation Effects via Single Event Effects within Avionics Equipment*

Aerospace Qualified Electronic Components (AQEC)



Start with the device manufacturer's "COTS" component

- ***Assure qualification, quality, reliability, design stability, etc.***
- ***Assess the component's capability to satisfy essential aerospace requirements***
- ***Evaluate part availability and business issues***

If necessary, issue a new part number and data sheet

AQEC Benefits and Status

Benefits

- Promotes communication between semiconductor device and aerospace industry
- Minimizes and reduces need for uprating or upscreening
- Part performance characterized for avionics
- DMSMS Management
  - Improves part availability
  - Component Roadmaps
  - Improves configuration control
- Enables system design tradeoffs (performance, lifetime, supply voltage, speed, temperature, etc.)
- Enables ‘higher-level’ system options

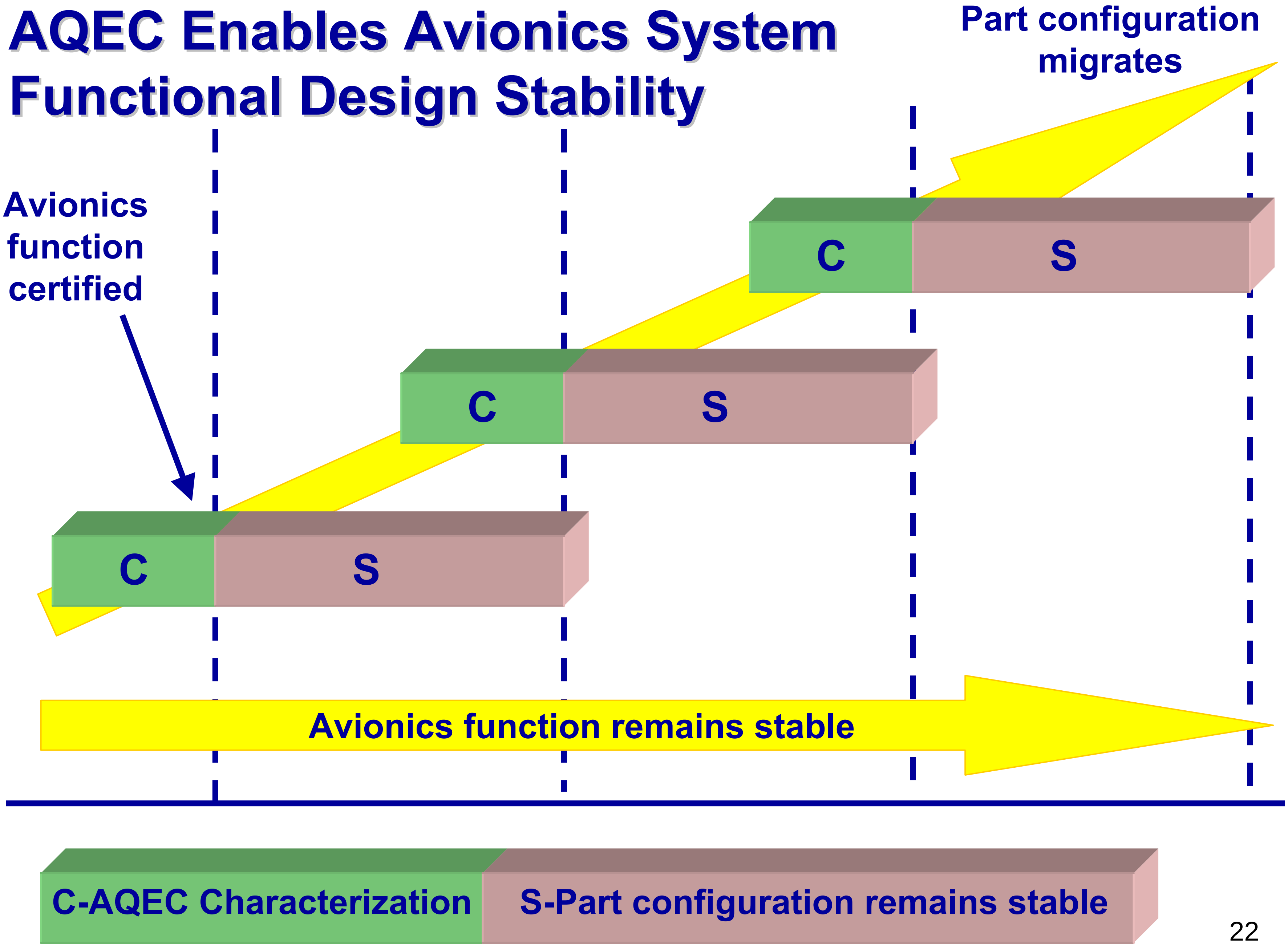
Who’s Involved

- Semiconductor device mfrs.
- Part distributors
- Avionics manufacturers
- Airframe integrators
- DoD
- NASA
- FAA
- Industry standards bodies

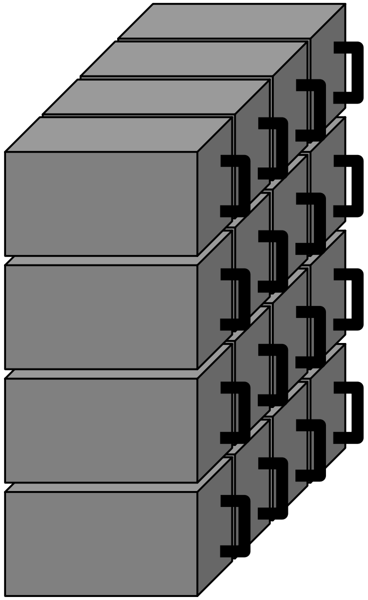
Status

- AQEC Definition approved by GEIA Avionics Process Management Committee (APMC)
- AQEC Standard out for vote by GEIA G-12, GEIA APMC, JEDEC JC 13
- Under consideration by IEC TC 107, Process Management for Avionics

AQEC Enables Avionics System Functional Design Stability

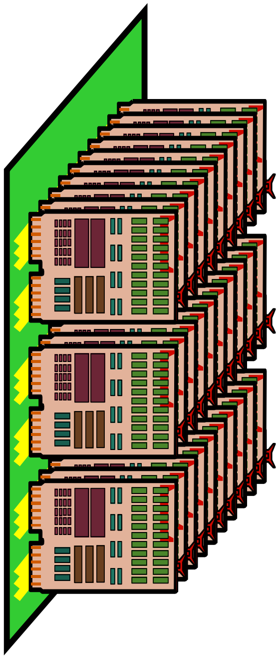


Architectural and System Options



Federated Systems

- System functions implemented by LRUs and related sensors, activators, etc.
- Distributed throughout the aircraft
- Parts in various environments



Integrated Modular Systems

- Central computing, shared across functions
- Maximum commonality of modules
- “Dumb” or “simple” sensors, actuators, backplanes, etc.
- Disposable or returnable elements
- Facilitates deferred maintenance

System Considerations

- The most common approach to obsolescence (DMS) is to find replacement parts. It cannot be sustained as use of sub-100 nm COTS increases
- Many component issues must be addressed totally or partially at the system architecture and design levels
- Two promising system design approaches (from a component point of view) are modular electronics and disposable modules
- *Why is aerospace the only major industry that still designs repairable circuit cards?*

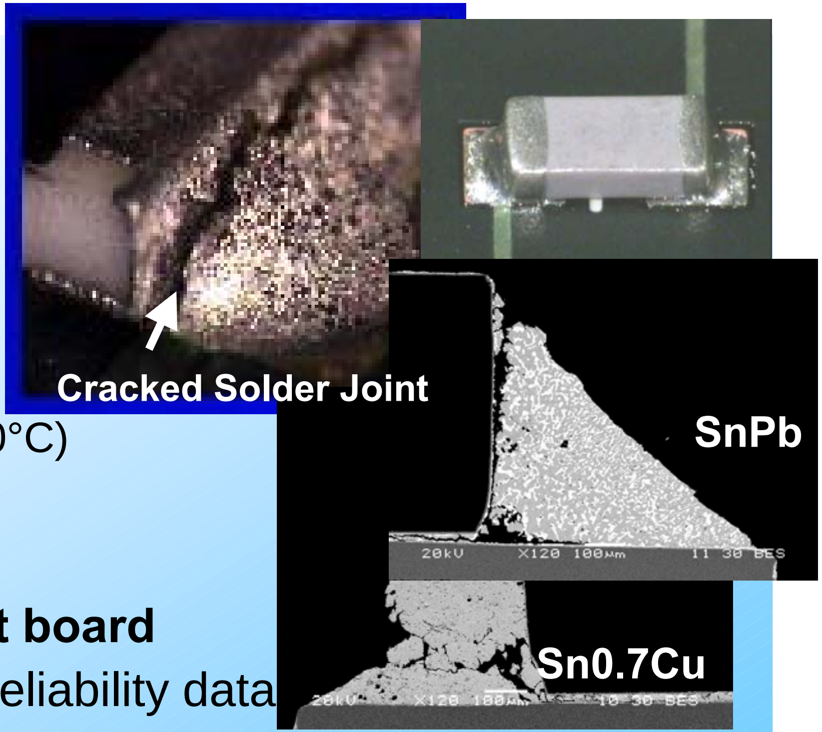
Lead-free Electronics

Directive 2002/95/EC:

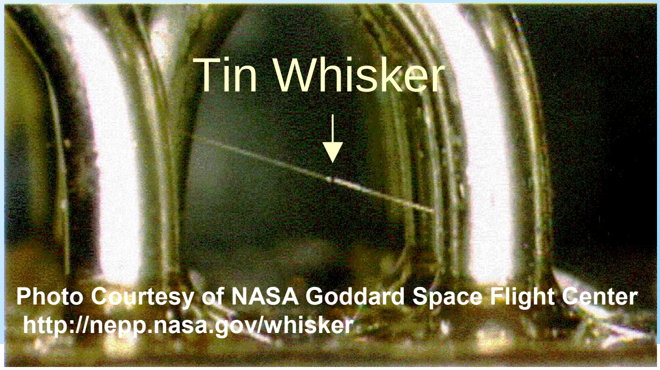
New electrical and electronic equipment put on the market after 1 July 2006 shall not contain lead or other hazardous materials

- **2002/95/EC is "official" only in Europe**
- **Although likely exempt from legislation, aerospace will be "swept along" in the transition**

There Will Be New Component Leads and Plating, Board Materials, and Assembly Materials and Processes



- **There is no single "drop-in" replacement for Sn-Pb (tin-lead) eutectic solder**
  - All viable Pb-free alternatives have higher melting points,
  - Reliability is inconsistent
- **Higher processing temperatures** (up to 260°C) **impact component design and reliability**
  - Potential latent defects
- **Mixture of metallurgies on a single circuit board**
  - Questionable reparability; no long term reliability data
  - Configuration control and obsolescence concerns



- **No consensus on test protocols yet**
- **Component suppliers are commonly (>50%) switching to pure tin plating**
  - Increased risk of **tin whisker** related failures

There Is No "Standard" Pb-free Alloy

Reflow Soldering

Material	EU	Japan
Sn-Ag-Cu	64 %	61%
Sn-Ag	8	9
Sn-Bi	4	0
Sn-Ag-Cu-Bi	-	5
Sn-Zn-Bi	-	9
Sn-Cu	-	1
Others	4	-
Don't know	20	15

Wave Soldering

Material	EU	Japan
Sn-Ag-Cu	42%	64%
Sn-Ag	17	20
Sn-Bi	8	5
Sn-Ag-Cu-Bi	4	-
Sn-Zn-Bi	-	2
Sn-Cu	-	1
Others	4	8
Don't know	25	-

Component Leads

Material	US	Japan	EU
Pure Sn	39 %	30%	26%
Pd-Au	1	4	15
Au-Ni	6	-	13
Sn-Ag-Cu	13	9	10
Sn-Ag	3	3	8
Sn-Bi	10	14	5
Sn-Cu	5	21	5
Ag	-	4	5
Don't know	-	-	13
Au	5	8	-
Sn-Ag-Cu-Bi	-	2	-
Ni-Pd	1	1	-
Sn-Zn-Bi	-	1	-
Ni-Pd-Au	8	-	-
Sn-Pb	5	-	-
Others	4	3	-

EU: Survey responses from 52 organizations

Japan: 95 assemblers and 100 suppliers

US: 71 suppliers

Sources (summarized by CALCE, U of MD):

- Japan Engineering and Information Technology Assocation Tech. Rep. "Result and Analysis of Pb-free Survey," pp. 157-171, 2002
- Soldertech at Tin Technology 2nd European Roadmap, 2003

Lead-free Electronics in Aerospace Project Working Group (LEAP WG)

- AIA - Aerospace Industries Association
- AMC - Avionics Maintenance Conference
- GEIA - Government Engineering and Information Technologies Association
- Includes all aerospace industry stakeholders
- Producing common industry standards (level playing field)
  - *GEIA-STD-0005-1,Performance Standard for Aerospace and Military Electronic Systems Containing Lead-free Solder*
  - GEIA-STD-0005-2, *Standard for Mitigating the Risks of Tin in High-Reliability Applications*
  - GEIA-HB-0005-1, *Program Management and System Engineering Guidelines for Managing the Transition to Lead-free Electronics*
  - GEIA-HB-0005-2, *Technical Guidelines for Using Lead-free Solder in Aerospace Applications*

Summary of Recommendations

Factor	Impact on Avionics System	Avionics System Design Response
Decreasing aerospace market share – Asian market growth	•Increasing obsolescence	• Use AQEC parts • Disposable modular assemblies
Changes in device definition and design methods	•Variations in device parameters •Loss of configuration control	• Use AQEC parts • Periodically re-evaluate parts to confirm critical parameters are acceptable • Anticipate parameter changes, e.g., speed • Streamlined re-certification processes
Elimination of lead	•Decreased reliability •Repairability issues •Configuration control issues	• Disposable modular assemblies • Use LEAP WG documents • Detailed knowledge of materials in avionics
Short service life	•Decreased reliability	• Disposable modular assemblies • Tradeoff temperature, power, speed, reliability
Narrow temperature range	•Decreased reliability	• Tradeoff temperature, power, speed, reliability • Disposable modular assemblies • Put complex functions in environmentally-controlled regions of the aircraft
Susceptibility to atmospheric radiation	•Increased single event rates	• Error-correcting code • Part redundancy • More testing • Use IEC TS 62396
Sub-100 nanometer feature sizes	•Increased integration of functions in smaller sizes	• Disposable modular assemblies • System-on-a-chip

Summary

- The challenges posed by the semiconductor device industry are not completely understood, even by those who are driving them.

- They are dynamic, and their rate of change is increasing.

- The semiconductor industry has limited motivation to consider the specific concerns of the aerospace industry

- Aerospace industry responses must be provisional, and open to modification as more information becomes available, or as current information becomes obsolete.

- Many COTS-DMS-Obsolescence problems must be addressed at the system level.